OPTIMIZATION OF PROCESSING PARAMETER FOR ENCHANCED GOOD QUALITY OF MANGO POWDER USING RESPONSE SURFACE METHODOLOGY

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ABSTRACT

The main purpose in mango powder production research is to identify the most influencing independent variables, their interactions and obtain the optimum value for the variables. Based on experimental design method, variables chosen were nozzle size, feed flow rate and inlet temperature. The respon chosen were moisture content and powder density. Manggo powder is produced with co-current spray dryer equipment model SD-04 while experimental result analysis is concluded using response surface methodology from 'Statsoft Statistica 1999' version 5.0 software. Response surface methodology were successfully used to link one or more responses to set of variables when firm interaction is known. Second degree polynomial equation is chosen to link responses behaviors to change of variable level. The equation model is tested with Anova analysis with 99 % degree of confidence. The response surface methodology output (contour plot) yields the optimum nozzle size, feed rate and inlet temperature of 1.6 mm, 27 ml/min and 190 ° C, will produce powder with 4.554 % moisture content and density of 1.372 g/cm^3. The powder quality produced is the best and fulfills food standards. The pareto charts shows that the most influencing and major variables is the nozzle size with effect of 3.525, and interaction variable of nozzle size and feed rate is second in influencing the powder quality.

Keywords : Experimental design; Response Surface Methodology; Anova Analysis; Interaction variables.

INTRODUCTION

Tropical fruit powders such as manggo powders have a large potential because of their inherent advantages of weight and product stability and because of the recent advances in flexible film packaging fruits powders have more potential in the market.Incresed consumer awarness of the exotic and mystical attractiveness of tropical fruits have extended the market globalization. Most recently trend in consumer patterns best described as the need for convenience foods, healty natural foods, increasing use of non-local products and the costly storage and handling of fresh fruits due to high perishability neccrssitate a need for an alternative product of the fruit juice powders which can be formulated into beverages or other fruit based product.

Spray drying is a technique means of converting fruits juices directly into powders or granulated form by spraying the fluid into a stream of hot air resulting fine particles, while still in suspension. The pulp to be dried is atomized 2 to 500 um, by high speed homogenization 6000-20000 rpm and sprayed into rapidly circulated heated air. Evaporation occurs within short drying times usually under 30 seconds and ensuring evaporative cooling with production of free flowing powders of low mosture content about 1 – 3.5% (1). A number of researches had been done on sparay drying of fruits and vegetables such as garlic, onoins, tomatoes (2) and durians (3). These researches showed that the powders produced, had high flavour profiles similar to that of the fresh products, were readily soluble in cold water, had low microbial population and long shelf life up to 2 years at 20 ° C and relative humiduty of 505 – 60% (4). The objective of this study was to optimize the processing parameters (independent variables) such as nozzle size, feed flowrate and inlet temperature for enhanced good quality of product and its effects on the properties product. Product quality analysis (respons) comprising of moisture content and powder density were analysed. The technique of response surface methodology (RSM) introduced first by Box and Wilson (5), is an effective and successful technique used to abrain optimum value and most influencing variable to a few set of variables that affects the value of any responses (6). With this method, it's easier to study the relation between variables verses previous techniques used by earlier researchers; which is by changing one variable and making others unchanged. Traditioanal methods of optimization which is single dimensional search involves extended experiment periods, difficulties in obtaining optimum value and interactive relations among variables, especially if several set of variables are involved (7). One variable at a time approach is also time consuming technique and fails to explain the interactions between and among the variables. In this communication a novel method of response surface technique has been applied to study the effect of processing parameters on powder quality. Central composite design has been applied to evaluate the optimal combinations of processing parameters.

Response surface methodology were successfully used to link one or more responses to set of variables when firm interaction is known. The first step in experimental strategy of RSM is to decide on a model form which expresses the response as a function of the independent varaibles in the process. This model provides the basis for new experimentation, which in turn may lead to a new model and the entire cycle is repeated. Conclusions can be drawn from the first experiments. This design employs response surface methodology which is a collection of statistical technique for designing experiments, building models, evaluating the effects of factors and searching optimum conditions for desirable responses (8).

MATERIALS AND METHOD

Preparation, processing and product analysis

Malaysian mango varieties of 'Mannifera indica L' or local name 'mangga siam' was used because of their fragnant smell, juiciness, fibreless flesh, sweetness and abundant availability in the market at the time of the research. Generally, mangoes when ripe have a high sugar content (15 – 20g/100g), low acid content (0.2 – 0.6g/100g), high water content (75 – 83g/100g), high caratenoids (5000 – 11000 IU/100g) and high vitamin C (Ascorbic acid 5 – 20 %), essential amino acids and minerals (9).

Food grade liquid glucose, maltodextrin and carboxy methyl cellulose (CMC) were used as anticaking agents or drying aids. The ratios of anticaking agent to the mango pulp consider as a constant parameters during the experimental work. Puree from manggo pulp wasprepared from the flesh of mangoes by using blender and fruit pulper juicer after blancing with hot water. The fragmentation and homogenization of the pulp was done in blender/homoginizer to ensure uniformity in the particle sizes, so as to avoids clogging of the spray dryer nozzle. The prepared pulp was mixed with ratio of water 1:1 (v/v). The puree was then preheated to 50 ° C and stirred well for about 30 minutes to lower the viscousness and improve drying efficiency (10). Anticaking agent of maltodextrin and CMC having very low hygroscopicity, minimal reducing sugar level, low browning tendency and low sweetness (11). The ratio of pulp : maltodextrin of 70:30 was chosen and CMC at 10:100g/g of CMC: pulp.

In these studies the main equipment spray dryer used is Buchi model SD-04 of Switzerland, which is a direct contact cocurrent. The dryer consists of essential components such as spary flow nozzle, drying chamber and product recovery system. Compressed air supply was provided at a pressure of 5 – 8 bar. The air was heated and introduced through a disperser around the atomiser creating a cocurrent flow of air and product with rapid surface evaporation. The mango products were collected at the outlet temperatures of 70 –95 ° C and product analysis were conducted. The moisture content was measured with moisture balance electric lab model ED-620 and theparticle density was measured by air pynometer model FD-05.

Experimental set up

The low, middle and high levels for all these variables were based on a prior screening done at laboratory and literature review and accordingly, 0.50, 1.00 and 1.50mm were chosen for the variable X_1 (nozzle size); 20.00, 25.00 and 30.00 ml/min for X_2 (feed flowrate) and 170.00, 190.00 and 210 ° C for X_3 (inlet temperature) as shown in Table 1.

Table 1: the levels of variables chosen for trials

Nozzle size, X_1 (mm)	Feed flowrate, X_2 (ml/min)	Inlet temperature, X_3 ($^\circ$C)
0.500 (-1)	20.00 (-1)	170.00 (-1)
1.00 (0)	25.00 (0)	190.00 (0)
1.50 (+1)	30.00 (+1)	210 (+1)

Experimental Design

The optimization process based on RSM method basically involves three major steps :performing the statistically designed experiments, estimating the coefficient in a mathematical and predicting the response, and checing the adequancy of the model (12).The equation model is tested with ANOVA analysis with 99 % degree of confidence.The RSM output such as contour plot and Pareto chart yields the optimum and most influencing variable to the powder quality. In the present study the independent variables were nozzle size, feed flowrate and inlet temperature, while the responses (Y_i) observed were moisture content and powder density. According to the central composite design, the total number of experiment combinations was $2^k + 2k + n_o$, where k is the number of independent variables and no is the number of repetion of the experiments at the centre point.
The variables X_i were coded as x_i according to the following equation:

$$X_i = (X_1 - X_o) / \Delta X_i; \; _i = 1, 2, 3,...k \qquad (1)$$

Where x_i = dimensionless coded value of the variable X_i,
X_o = the variable of X_i at centre point,
ΔX_i = step change

The specific codes are :
x_1 = (nozzle size (mm) – 1.00) / 0.50
x_2 = (feed flowrate (ml/min) – 25.00)/ 5.00
x_3 = (inlet temperature ($^\circ$C) – 190.00) / 20.00
Where x_1, x_2 and x_3 are coded values of the variables nozzle size, feed flowrate and inlet temperature respectively.

Second degree polynomial equation is chosen to link responses behaviours to change of variable level.

$$Y_u = \beta_0 + \sum_{i=1}^{k} \beta_i X_{ui} + \sum_{i=1}^{k} \beta_{ii} X_{ui}^2 + \sum \sum_{i<j}^{k} \beta_{ij} X_{ui} X_{uj} \qquad (2)$$

where Y_u = predicted response u, β_0 = offset term, β_i = linear term , β_{ii} = squared term, β_{ij} = interaction term

There are three variables are involved and hence k takes the value of 3. Thus, by subsitituting the value 3 for k, equation (2) becomes:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 + \beta_{11} X_1^2 + \beta_{22} X_2^2 + \beta_{33} X_3^2 \qquad (3)$$

The actual design experiment is shown in Table 2. By solving equation (3), it was found that a total of 16 runs was necessary in order to optimize processing parameters for enchanced good quality of mango powder that involved three independent variables, viz., nozzle size, feed flowrate and inlet temperature, wherein each variable has its own effect on the responses, viz., mosture content and powder density. The experiments were performed in duplicate and the mean values were taken for the analysis. The regression equation were optimized by iteration method to get the optimum values (13). Analysis of variance, ANOVA, was perform on the data.The design experiments were carried out using the Design Expert Statsoft software 'Statistica' version 5.0 1999.

Table 2: Experimental plan for optimization of processing parameter for enchanced good quality of mango powder.

Trial number (Run)	Independent variables		
	Nozzle size (mm)	Feed flowrate (ml/min)	Inlet temperature (°C)
1	0.5	20.0	170.0
2	0.5	20.0	210.0
3	0.5	30.0	170.0
4	0.5	30.0	210.0
5	1.5	20.0	170.0
6	1.5	20.0	210.0
7	1.5	30.0	170.0
8	1.5	30.0	210.0
9	1.0	25.0	190.0
10	0.1	25.0	190.0
11	1.9	25.0	190.0
12	1.0	16.2	190.0
13	1.0	33.8	190.0
14	1.0	25.0	154.7
15	1.0	25.0	225.3
16	1.0	25.0	190.0

RESULTS AND DISCUSSION

The results of this study showed that production of mango powder is totally depend on the nozzle size, feed flowrate and inlet temperature. The investigation was aimed at studying the effects of varying levels of independent variables on the enchanced good quality of product. Responses surface methodology employing Box-Benken design for three indepenfent variables was taken to obtain the combination of values that optimizes the response within the region of the 3-D observation space, which allows one to design a minimal number of experimental runs. The model also evaluated the effect of each independent variable to a response, singly and in combination with other variables, which is not otherwise feasible. The experimental value and predicted response for the 16 trials runs carried out are presented in table 3.

Table 3:Experimental and theoretical predicted values for moisture content and powder density

Trial No.	Moisture content (%)		Powder Density (g/cm^3)	
	Experimental	Predicted	Experimental	Predicted
1	7.6000	7.1607	1.9760	1.8399
2	6.7000	6.0058	1.5530	1.5290
3	10.5000	8.8779	2.0730	1.9524
4	9.0000	7.9730	1.9840	1.8515
5	5.8000	5.6806	1.5260	1.5170
6	4.2000	4.6757	1.3980	1.3771
7	5.1000	4.6478	1.4470	1.3294
8	4.6000	3.8929	1.4050	1.3995
9	3.4000	3.4764	1.2080	1.2174
10	7.2000	8.7866	1.8800	2.0453
11	4.0000	3.8936	1.3460	1.3635
12	5.7000	5.5790	1.4690	1.5075
13	4.8000	6.4013	1.4820	1.6263
14	6.2000	7.1287	1.5250	1.6726
15	4.9000	5.4432	1.4260	1.4601
16	3.4000	3.4764	1.2080	1.2174

In the present investigation, it was observed that the responses changed significantly with variation in the three variables. From the experimental data , the good quality product of moisture content and powder density could be produced was 3.400% and 1.208 g/cm^3 respectively at nozzle size 1.00mm, feed flowrate 25.00 ml/min and inlet temperature 190 ° C. Using multiple regression analysis on the experimental data, the following second order polynomial equations were found to explain the quality of powder production, equation (3) can be given as :

$$Y_1 = 3.4764 + 4.0136X_1 - 1.4201X_2 + 3.6980X_3 - 0.2750X_1X_2 + 0.0006X_2X_3 - 0.8576X_1X_3 + 3.6980X_1^2 + 0.0325X_2^2 + 0.0023 X_3^2 \quad (4)$$

$$Y_2 = 1.2174 - 1.7721X_1 - 0.2843X_2 - 0.1261X_3 - 0.0291X_1X_2 + 0.0050X_2X_3 + 0.0045X_1X_3 + 0.6273X_1^2 + 0.0045X_2^2 + 0.0003X_3^2 \quad (5)$$

where Y_1 is the pridicted moisture content (response 1) and Y_2 is the predicted powder density (response 2). The coefficients of the equation (4) – (5) are listeb in table 4. The analysis of variance table displaying the total, regression and error sum of square is shown in table 5 and table 6. The summary of the analysis of variance for all the two parameters are given in tables 5 – 6.

Table 4: Coefficients of the model

Nilai angkatap	Kandungan lembapan	Ketumpatan serbuk
β_0	3.4764	1.2174
β_1	4.0136	-1.7721
β_2	-1.4201	-0.2843
β_3	3.6980	-0.1261
β_{11}	3.6980	0.6273
β_{22}	0.0325	0.0045
β_{33}	0.0023	0.0003
β_{12}	-0.2750	-0.0291
β_{13}	-0.8576	0.0045
β_{23}	0.0006	0.0050

Table 5: ANOVA for the moisture content (quadratic response surface model fitting

Source	Sum of square	Degree of freedom	Mean square	F value	R^2
Model	47.9818	9	5.3313	2.762	0.8055
Error	11.5825	6	1.9300		
Total	59.5644	15			

Table 6: ANOVA for the powder density (quadratic response surface model fitting)

Source	Sum of square	Degree of freedom	Mean square	F value	R^2
Modeli	0.9726	9	0.1081	4.6864	0.8754
Error	0.1384	6	0.0231		
Total	1.1110	15			

The coefficient of determination (R^2) for moisture content and powder density are 0.8055 and 0.8754 respectively. The value of R^2 is a measured of total variation of observed values about the mean explained by the fitted model which is often expressed in percentage. These values of R^2 are greather than 80% show a good agreement between experimental data and predicted values.

Statistical testing of the model was done by the Fisher's statistical test for analysis of variance (ANOVA) and the results are shown in table 5 dan table 6. The F value is the ratio of the mean square due to regression to the mean square due to error.The value of F is compared to the table value $F_{(p-1,N-p,\alpha)}$. If the value of F smaller than $F_{(p-1,N-p,\alpha)}$, then the null hypothesis is accepted at the α level of significance. If the null hypothesis is true, it's means that the model is a good predictor of the experimental data. From ANOVA table, the value of F of mositure content and powder density are 2.762 and 4.6864 respectively. These F values are smaller than tabulated $F_{(9,6,0.01)}$,which is 7.980. These is means the null hypothesis is

true and validates experiment response behavior could be represented by the second order polynomial equation.
The fitted model from equation (4) and (5) now can be used to map empirically the response function over the experimental region. The three dimensional contour plot helps in assessing the effect of any two variables in combination on the product quality. The effects of nozzle size and feed flowrate and nozle size and inlet temperature, and feed flowrate and inlet temperature on the response can be obtained. Contour plots are shown in Figs. 1-3 for response moisture content and Figs. 4- 6 for response powder density. The coordinates of the stationary point are called optimum point.
From Figs. 1- 3 shown that the good quality of mosture content of 4.554% can be got at a nozzle size range 1.00 mmm to 1.80mm, feed flowrate (22.00 to 28.00 ml/min) and inlet temperature between 170 ° C to 220 °C. The optimum values of nozzle size, feed flowrate and inlet temperature can be got using this three dimensional contour plot for equation (4) followed by the solving of inverse matrix. The optimization values for a moisture content of 4.554% was found to be nozzle size 1.60 mm, feed flowrate 27.00 ml/min and inlet temperature 190 °C.
The optimum conditions of nozzle size, feed flowrate and inlet temperature for good quality of powder density can be got from three dimensional contour plot from Figs 4 – 6. The powder density 1.372 g/cm^3 can be obtained at a nozlle size ranging from 1.00 mm – 1.80 mm, at a feed flowrate between 18.00 to 32.00 ml/min and inlet temperature at a 170.00 °C and 210 °C. Optimization results by solving the inverse matrix from equation (5) shows a good powder density 1.372 g/cm^3 at nozzle size 1.60mm, feed flowrate 28 ml/min and inlet temperature 190 °C.
The Pareto charts from Figure 7 show the nozzle size variable is the most important and influenced with the effect values of 3.525. Interactive variable between nozzle size and feed flowrate are second while inlet temperature is fourth in influencing powder quality. With absolute effect value of 0.075, interactive variable between nozzle size and inlet temperature is assumed not influencing the products response value.

CONCLUSION

The Response Surface Methodology involving an experimental design and regression analysis was effective in finding the optimum point of the three independent variable, and in assessing their effects on the two responses considered. Fruit powder production is determined by nozzle size, feed flowrate and inlet temperature variables. This shows that variables factors and level selection meets experiment designing concept.The second order polynomial equation model estimation which validility is agreed upon is estimated using Anova statistical testing and yields 99% degree of confidence of response behaviours to variables.The optimum values of nozzle size, feed flowrate and inlet temperature which are 1.60 mm, 27 ml/min and 190 ° C respectively to produce the best quality powder with 4.554% moisture content and 1.372 g/cm^3 powder density. The powder quality values meet the recommended food standard. The combination of these three variables must be set at the level maximum for nozzle size and middling for feed flowrate and inlet temperature. The level setting of each variable meets previous experiments results.

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